TECHNICAL SUPPORT DOCUMENT

MIDWEST SUBREGIONAL MODELING:

1-HOUR ATTAINMENT DEMONSTRATION FOR LAKE MICHIGAN AREA

Illinois Environmental Protection Agency
Indiana Department of Environmental Management
Michigan Department of Environmental Quality
Wisconsin Department of Natural Resources

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EXECUTIVE SUMMARY

On December 16, 1999 (64 FR 70496, 64 FR 70514, 64 FR 70531), the U.S. Environmental Protection Agency (USEPA) published notices of proposed rulemaking conditionally approving the 1-hour ozone attainment demonstration for the severe nonattainment areas in northeastern Illinois, northwestern Indiana, and southeastern Wisconsin. The proposed conditional approval is based, in part, on a commitment by these States to submit an updated ozone attainment demonstration State Implementation Plan (SIP) and a post-1999 Rate of Progress (ROP) Plan by December 31, 2000. The purpose of this document is to summarize the results of the photochemical modeling and other analyses used to support the updated ozone attainment demonstration.

The updated attainment strategy consists of four sets of controls: (1) Federal Clean Air Act controls, (2) State ROP emission reductions, (3) the Tier II/Low S program, and (4) regional NOx controls. The modeling shows that these emission reductions will result in widespread ozone decreases and isolated ozone increases. Ozone decreases occur throughout much of the modeling domain, including areas with high base concentrations. Ozone increases are limited mostly to urban areas, and generally occur on days with lower 1-hour concentrations.

The modeled attainment tests show that Federal Clean Air Act controls alone will reduce ozone concentrations, but do not, by themselves, provide for attainment of the 1-hour NAAQS everywhere in the Lake Michigan area. The full set of controls noted above provide for attainment of the 1-hour NAAQS throughout the Lake Michigan area

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Section 1
Introduction

The purpose of this document is to summarize the updated 1-hour ozone attainment demonstration for the Lake Michigan area. The attainment demonstration is based on a state-of-the-art photochemical modeling analysis plus supplemental weight-of-evidence information (e.g., air quality analyses).

The modeling is consistent with the USEPA guidance documents entitled "Guideline for Regulatory Application of the Urban Airshed Model", July 1991 and "Guidance on Urban Airshed Model Reporting Requirements for Attainment Demonstrations", March 1994. The attainment test is based on the USEPA guidance document entitled "Guidance on Use of Modeled Results to Demonstrate Attainment of the Ozone NAAQS", June 1996. As discussed in the following sections, the modeled attainment demonstration for the Lake Michigan area is based on; (1) Federal Clean Air Act controls, (2) State ROP emission reductions, (3) the Tier II/Low S program, and (4) regional NOx controls.

In general, an attainment demonstration SIP includes a modeling analysis component showing how the area will achieve the standard by its attainment date and the emission control measures necessary to achieve attainment. Another component of the attainment demonstration SIP is a motor vehicle emissions budget for transportation conformity purposes. Transportation conformity is a process for ensuring that States consider the effects of emissions associated with new or improved federally-funded roadways on attainment of the standard. As described in section 176(c)(2)(A) of the Clean Air Act, attainment demonstrations necessarily include the estimates of motor vehicle emissions that are consistent with attainment, which then act as a budget or ceiling for the purposes of determining whether transportation plans and projects conform to the attainment SIP. Each State is responsible for submitting a transportation conformity budget.

Section 2 reviews the regulatory history leading to this submittal. An overview of the Midwest subregional modeling is provided in Section 3. Sections 4 and 5 address the basecase and strategy modeling results, respectively. The application of the attainment tests are presented in Section 6. A summary is provided in Section 7.

Section 2
Background

The persistent, regional nature of the ozone problem in the Lake Michigan area has necessitated a new air quality planning approach. During the past two decades, the Lake Michigan area, which includes portions of the States of Illinois, Indiana, Michigan, and Wisconsin, experienced exceedances of the 1-hour National Ambient Air Quality Standard (NAAQS) for ozone[1].

In recognition of the need for a regional solution, the Lake Michigan States began to work together in 1988 on their common air quality problem. Prior to this collaborative State effort, USEPA and the States of Illinois and Wisconsin were engaged in litigation concerning ozone control in the Chicago area. These two activities led to a Memorandum of Agreement (MOA) signed by USEPA and the four Lake Michigan States in September 1989. The MOA established the Lake Michigan Ozone Study (LMOS). The goals of the LMOS were to collect air quality, meteorological, and emissions data bases; develop and evaluate a comprehensive modeling system; and deliver the model to the States. A major field program was conducted during the summer of 1991 to collect the necessary technical data. The next couple of years were spent on model development, model evaluation, and data analyses. On December 15, 1994, USEPA determined that the model was "...performing in an acceptable manner and may be used for regulatory purposes."

In 1990, Congress amended the Clean Air Act (CAA) to address better, among other things, continued nonattainment of the 1-hour ozone NAAQS[2]. The 1990 Amendments

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On July 18, 1997, USEPA replaced the 1-hour ozone standard with an 8-hour standard (62 FR 38856). At that time, USEPA also announced that the 1-hour standard would continue to apply in an area until it attained the 1-hour standard. In subsequent rulemaking actions, USEPA revoked the 1-hour standard in nearly 3000 counties nationwide. On May 14, 1999 (and modified on October 29, 1999), however, the U.S. Court of Appeals for the D.C. Circuit remanded the new 8-hour standard (American Trucking Association v. USEPA ,175 F.3d 1027). In light of the 1-hour revocations, this left many areas with no enforceable ozone standard. (Note, USEPA never revoked the 1-hour ozone standard in about 200 counties, including the 16 severe nonattainment counties in the Lake Michigan region; thus, this standard has and continues to apply there.) On July 5, 2000, USEPA reinstated the 1-hour standard in those counties where it had been previously revoked.

2 An area exceeds the 1-hour ozone standard each time an ambient air quality monitor records a 1-hour average ozone concentration above 0.124 ppm on any day. An area violates the standard if, over a consecutive 3-year period, more than 3 daily exceedances occur at any monitor in the area or in its immediate downwind environs. The highest of the fourth-highest daily peak ozone concentrations over the 3 year period at any one monitoring site in the area is called the design value for the area.

required States and USEPA to review and, if necessary, revise the designation of areas. Areas designated as nonattainment were divided into five primary classifications based on current air quality. Certain counties in the Lake Michigan area were classified as marginal, moderate, or severe nonattainment. The 1990 Amendments established specific planning requirements for each classification, including the need for rate of progress (ROP) reductions in ozone precursor emissions and a demonstration of attainment. The ROP and attainment demonstration SIP submittals for severe nonattainment areas were required by November 1994. The applicable attainment date for the Lake Michigan severe nonattainment area is 2007.

A second MOA was signed by the States in 1991 to establish the Lake Michigan Ozone Control Program (LMOP), which represents the regulatory continuation of LMOS. The goals of the LMOP are to develop, submit, and implement an effective regional attainment strategy to enable the Lake Michigan States to comply with the requirements of the 1990 Amendments. As part of this planning effort, two key findings were noted (LADCO, 1995):

(1) Urban VOC emission reductions are effective in lowering ozone concentrations in the urban nonattainment areas, whereas regional NOx emission reductions both decrease and, on some days, increase ozone concentrations. Ozone decreases occur throughout much of the modeling domain, including areas with high base concentrations, while ozone increases are limited mostly to urban areas. Because it was not clear whether the ozone increases cause or contribute to exceedances of the ozone NAAQS in these areas, the Lake Michigan States petitioned for and USEPA approved a waiver from certain NOx control requirements of the 1990 Amendments (61 FR 2428).[3]

(2) Incoming (transported) ozone levels to the Lake Michigan area are on the order of 70 - 110 ppb on some hot summer days. The modeling showed that it will take significant reductions in both local ozone precursor emissions and incoming (transported) ozone and ozone precursor concentrations for the States to attain the NAAQS.

Recognizing the transport problem, USEPA established a two-phase program for states to develop approvable ozone SIPs. In a policy memorandum dated March 2, 1995,

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USEPA granted the waiver on a contingent basis. In the notice of final rulemaking on the waiver, USEPA stated that it expected the Lake Michigan States to incorporate OTAG modeling results and control recommendations in the development of attainment plans. USEPA further indicated its intent to review these attainment plans, and the associated modeling, to determine if the waiver should be continued, altered, or removed. In light of the NOx controls for certain sources included in this updated 1-hour attainment demonstration, the waiver is now moot for these sources.

USEPA outlined the major elements of this program. Phase I required states to complete pre-November 1994 SIP requirements, submit regulations sufficient to meet the initial ROP requirements, and submit modeling analyses. (Note, the Lake Michigan States have complied with the Phase I requirements.) Phase II called for a two-year consultative process (1995-1996) to assess national/regional strategies to address ozone transport in the eastern U.S., and subsequent revisions of local control plans, as necessary, based on any new national/regional strategies.

To accomplish the Phase II consultative process, the Environmental Council of the States (ECOS), in conjunction with USEPA, established the Ozone Transport Assessment Group (OTAG). The goal of OTAG was to "...identify and recommend a strategy to reduce transported ozone and its precursors which, in conjunction with other measures, will enable attainment and maintenance of the national ambient ozone standard in the OTAG region." During its two years of operation from mid-1995 through mid-1997, OTAG developed the most comprehensive, up-to-date assessment of ozone transport in the eastern U.S.

In June 1997, OTAG concluded and provided USEPA with recommendations regarding ozone transport. OTAG generally concluded that transport of ozone and the precursor NOx is significant, and should be reduced regionally to enable States in the eastern half of the country to attain the ozone NAAQS. In recognition of the length of the OTAG process, in a December 29, 1997 memorandum, Richard Wilson, USEPA's then Acting Assistant Administrator for Air and Radiation, provided until April 1998 for States to submit the following elements of their attainment demonstration SIPs for serious and severe nonattainment areas: (1) evidence that the applicable control measures in subpart 2 of part D of title I of the Clean Air Act were adopted and implemented, or were on an expeditious course to being adopted and implemented; (2) a list of measures needed to meet the remaining ROP emissions reduction requirement and to reach attainment; (3) for severe areas only, a commitment to adopt and submit the control measures necessary for attainment and the ROP plans through the attainment year by the end of 2000; (4) a commitment to implement the SIP control programs in a timely manner and to meet ROP emissions reductions and attainment; and (5) evidence of a public hearing on the State submittal. (This submission is sometimes referred to as the Phase II submission.) Motor vehicle emission budgets can be established based on a commitment to adopt the measures needed for attainment and identification of the measures needed. Thus, State submissions due in April 1998 under the Wilson policy should have included a motor vehicle emissions budget.

Building upon the OTAG recommendations and technical analyses, in November 1997, USEPA proposed action addressing the ozone transport problem. In its proposal, USEPA found that current SIPs in 22 States and the District of Columbia (23 jurisdictions) were insufficient to provide for attainment and maintenance of the 1-hour standard because they did not regulate NOx emissions that significantly contribute to ozone transport (62 FR 60318, November 7, 1997). USEPA finalized that rule in September 1998, calling on the

23 jurisdictions to revise their SIPs to require NOx emissions reductions within each State to a level consistent with a NOx emissions budget identified in the final rule (63 FR 57356, October 27, 1998). This final rule is commonly referred to as the NOx SIP call. In view of pending challenges to the final rule, the Court of Appeals for the District of Columbia Circuit on May 25, 1999, stayed submission of revised State Implementation Plans in response to the NOx SIP Call pending further of the court. On March 3, 2000, the Court largely upheld the final rule, with certain exceptions, and on June 23, 2000, it lifted the stay.

In April 1998, the States of Illinois, Indiana, and Wisconsin submitted their Phase II SIPs. Under the Clean Air Act, USEPA is required to approve or disapprove a State's submission no later than 18 months following submission. (The statute provides up to 6 months for a completeness determination and an additional 12 months for approval or disapproval.) On December 16, 1999 (64 FR 70496, 64 FR 70514, 64 FR 70531), USEPA proposed to take action on these SIPs. USEPA proposed to conditionally approve the SIPs. The proposal is based on the submitted (April 1998) modeling analysis and on the States' commitments to adopt and submit an updated ozone attainment demonstration SIP and post-1999 ROP plan, including the necessary State air pollution control regulations to complete the attainment demonstration and ROP plans by December 31, 2000. This document summarizes the modeling to support the updated ozone attainment demonstration.

Section 3
Overview of Modeling

A state-of-the-art modeling analysis was performed to support the updated 1-hour ozone attainment demonstration[4]: The variable-grid Urban Airshed Model, version 1.24 (UAM-V) was used for the analysis. This is the same version of the model that was used during OTAG and in the previous Midwest subregional modeling analyses (LADCO, 1998a; LADCO, 1998b; LADCO, 1999a).

The modeling domain and grid configuration was established based on consideration of areas of high ozone concentrations in the Lake Michigan States and possible upwind source areas impacting these high concentration areas. The primary domain, which is referred to as Grid M, is shown in Figure 1. (Note, the "purple" shaded area represents the Lake Michigan subdomain for which various metrics and the attainment test measures were developed.) The specifics of this grid are as follows:

Horizontal Resolution:	1/9° lat x 1/6° long (approx. 12 km x 12 km) - all runs 1/27° lat x 1/18° long (approx. 4 km x 4 km) - select runs
Vertical Resolution:	7 vertical layers (0 - 50, 50 - 100, 100 - 250, 250 - 500,

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4 The modeling addressed in this document represents the second round of subregional modeling to support the 1-hour attainment demonstration. The first round of modeling also included basecase, strategy, and sensitvity runs (see LADCO, 1999b). Although the second round of modeling provides the most up-to-date results (e.g., emissions inventory revisions were made between the first and second round of modeling), there were a number of useful findings from the first round of modeling, including:

(1) UAM-V and CAMx produce similar (reasonable) basecase results and respond similarly to reductions in VOC and NOx emissions. (Based on this finding and the desire to rely on a single model in the updated attainment demonstration, a decision was made to use just UAM-V in the second round of modeling).

(2) The Ozarks isoprene "volcano" has a relatively small, yet noticeable impact in the Lake Michigan area on some days. (Based on this finding and the results of the preliminary OZIE analyses [LADCO, 1999c], a decision was made to reduce the Ozarks biogenic isoprene emissions by a factor of two.)

(3) Application of USEPA's attainment tests shows noticeable differences between control strategies. The lowest control scenario (Clean Air Act controls) produces the least favorable attainment showing, while the most control scenarios (0.25 utility control plus Tier II/Low S; and the SIP Call controls) produce the most favorable attainment showing.

500 - 1500, 1500 - 2500, and 2500 - 4000 m)
(see LADCO, 1999d)

SW Corner:	-92 W, 35 N
NE Corner:	-82.28 W, 45.37 N
No. of Grid Cells:	58 x 93 x 7 (12 km)
	175 x 280 x 7 (4 km)

Subregional modeling is necessary to assess ozone concentrations on both the local urban scale and the larger regional scale. As such, this modeling can be used to support urban area attainment demonstrations and address transport. To assess the effect of grid resolution, a few runs were also performed with finer horizontal grid resolution (i.e., 4 km). The results of the 4 km runs, as discussed below, are generally consistent with those of the 12 km runs.

Four episodes were modeled[5]:

June 22 - 28, 1991
July 14 - 21, 1991
June 13 - 25, 1995
July 7 - 18, 1995

These episodes were selected because they are representative of typical ozone episodes in the Lake Michigan area; they reflect a variety of meteorological conditions (see trajectory plots in Figure 2); there is an intensive data base available from 1991 LMOS field program; and they were previously modeled as part of the LMOS/LMOP (1991 episodes) and OTAG (July episodes) studies. Maps of the peak daily 1-hour observed ozone concentrations for each episode are provided in Figure 3.

There are three key model inputs: emissions, meteorology, and boundary conditions. The development of these inputs for the current model basecase is discussed briefly here.

> Emissions: UAM-V requires a regional inventory of gridded, hourly emissions estimates for speciated volatile organic compounds (VOC), oxides of nitroggen (NOx), and carbon monoxide (CO). The emissions were processed with the EMS-95 emissions model. Emissions inventories were prepared for a 1996 base year, a 2007 base year, and several 2007 strategy/sensitivity scenarios (LADCO, 1999e). The inventories include 1996 state periodic inventory data for point and area sources, updated state transportation data, excess NOx emissions produced by heavy-duty diesel vehicles as a result of built-in "defeat" devices, updated growth

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Preliminary modeling was also performed for the August 22 - 26, 1991 episode, but the results were found to be unacceptable. Thus, this episode was not included in the current modeling analysis.

and control data, and USEPA's latest emissions credits for the Tier II/Low S program. Temperatures from the RAMS3a meteorological modeling were used in the calculation of motor vehicle and biogenic emissions. Biogenic emissions were based on USEPA's BEIS2 model, with an adjustment of the isoprene emissions in the Ozarks based on the OZIE field data. A summary of the VOC and NOx emissions is provided in Table 1.

Of the approximately 2000 stacks in the elevated point source file, 134 were flagged as plume-in-grid (PiG) sources for the photochemical grid modeling. These 134 stacks were selected based on magnitude of NOx emissions (i.e., the top 100 ranked stacks) and location (i.e., 34 of the next top ranked stacks in the Lake Michigan and St. Louis areas).

Meteorology: UAM-V requires 3-dimensional hourly values of winds, temperatures, pressure, water vapor, vertical diffusivity, and, if applicable, clouds and precipitation. Most meteorological inputs were developed through prognostic meteorological modeling with RAMS3a performed by ASTeR for the 1991 episodes (ASTeR, 1997), and by Wisconsin DNR for the 1995 episodes (WDNR, 1996). Limited four-dimensional data assimilation was performed (i.e., analysis nudging using only every 12-hour National Weather Service [NWS] rawinsonde observations). Cloud and precipitation fields were developed based on observed NWS data.

A preliminary evaluation of the meteorological model results showed adequate representation of the general airflow features, and good agreement between modeled and measured wind speeds, temperatures, and water vapor (SAI, 1996; ASTeR, 1997). These findings suggest that the model results are reasonable and can be used to provide meteorological inputs for UAM-V. Errors or uncertainties in the meteorological fields, however, may affect the UAM-V results.

Given differences in the coordinate systems between RAMS3a (rotated polar stereographic) and UAM-V (latitude-longitude), and in the horizontal and vertical grid structure between the two models, the RAMS2UAMV conversion program was run to map the RAMS output data to the UAM-V grid configuration. For vertical diffusitivies, the mapped meteorological fields and RAMS-based TKE's were used to derive the necessary UAM-V input using the Ulrickson method (SAI, 1998a).

Boundary Conditions: Boundary conditions were developed by applying UAM-V over the OTAG domain at 36 km grid resolution. The OTAG domain modeling used the UAM-V (and not the SAI-modified) photolysis rates, and adjusted "clean" boundary and top concentrations (i.e., increased by 50%) based on OTAG and LMOS data analyses.

In addition, to establish an appropriate model basecase, a thorough examination of several key modeling system parameters was performed. These parameters, and the results of the examinations, are as follows

Photolysis Rates: An important component of the chemical mechanism in the model are the photolysis reaction rates. The photolysis rates in UAM-V are derived using a light model developed by Shippneck and Green (1982). Recent literature indicates that the assumed light model inputs in UAM-V may be too low (Dickerson et al, 1997). A series of sensitivity runs were performed to examine alternative sets of photolysis rates (LADCO, 1999f): UAM-V rates, modified UAM-V rates (SAI, 1998b), and rates based on the TUV model (Madronich, 1999). These runs found that the modified UAM-V rates produced the highest ozone concentrations, while the UAM-V rates produced the lowest ozone concentrations. A decision was made to use the TUV-based rates for the following reasons: (1) undergone several field study comparisons of modeled and measured photolysis rates; (2) incorporate several state-of-the-art radiative transfer schemes from different research groups; (3) incorporate an extensive, up-to-date database of cross-sections and quantum yields: and (4) consistency with the CAMx model.

Deposition: Ozone and ozone precursor concentrations can be reduced through surface deposition. The dry deposition algorithm in UAM-V is based on the scheme in the RADM model described by Wesely (1989). Previous UAM-V modeling in the Lake Michigan area indicated a possible problem with the deposition treatment in the model (i.e., excessive deposition may be responsible for a "fall-off" in ozone concentrations over rural, agricultural portions of the modeling domain). Marv Wesely and SAI were asked to review and comment on the deposition treatment in the model. Wesely maintained that the ozone deposition velocities calculated by the model were appropriate for the most common midwest crop types (corn and soybeans), but that the velocities "...could be reduced if soil moisture stress is likely..." (Wesely, 1998). SAI identified a number of possible improvements to the deposition treatment in the model, and also noted that "(i)f indications of moisture stress are present in the current modeling periods, activation of the moisture stress algorithm within UAM-V should be considered"(SAI, 1998c). Valid values for the moisture stress flag in the model are 0, 1, or, 2, with 0 being the default (not moisture stressed) and 2 being the highest level of moisture stress. According to the "Weekly Weather and Crop Bulletin", the crop moisture index over a large area of midwest ranged from slightly to excessively dry during the June and July 1991 episodes, but only slightly dry during the June and July 1995 episodes. Consequently, it was decided that the highest level of moisture stress ("stress = 2") was appropriate for the 1991 episodes, and the default level for the 1995 episodes ("stress = 0").

SAI also reviewed and recommended a change for the calculated aerodynamic resistance to deposition during nighttime hours (SAI, 1998d). Specifically, a revision was made in the calculation of the Ri number, which represents the stability of the atmosphere. This revision results in considerably less deposition at night and only slightly less deposition during the day

Clouds: Cloud cover is used in the model to attenuate photolysis rates based on a modified version of the approach in the RADM model. This modified approach was used in the OTAG modeling. The cloud cover adjustment factors are as follows:

Cloud Cover	OTAG Adjustment Factor	RADM Adjustment Factor
0.0	0.0	1.00
0.1	0.0	0.96
0.2	0.0	0.92
0.3	0.0	0.88
0.4	0.0	0.84
0.5	0.0	0.80
0.6	0.0	0.76
0.7	0.72	0.72
0.8	0.68	0.68
0.9	0.64	0.64
1.0	0.59	0.59

As can be seen, an adjustment was only made for grid cells during hours with at least 70% cloud cover. A sensitivity test was performed with the full set of RADM adjustment factors. Surprisingly, the model was quite sensitive to cloud cover adjustments made for grid cells during hours between 10% and 70% cloud cover. Concentration differences were as much as 10 - 20 ppb over large portions of the domain. Given the uncertainty of effects at lower cloud cover, however, a decision was made to rely only on the adjustment factors for higher cloud cover, consistent with the OTAG modeling.

Section 4
Basecase Modeling

The purpose of basecase modeling is to evaluate model performance by comparing observed and modeled concentrations. The model performance evaluation consisted of comparisons of the spatial pattern, temporal profile, and magnitude of modeled and measured 1-hour (and 8-hour) ozone concentrations.

It should be noted that the 1996 base year emissions are expected to be reasonably similar to (albeit slightly lower than) 1995 emissions, but significantly lower than 1991 emissions. Thus, use of the 96bas emissions in the performance evaluation is appropriate for the two 1995 episodes, but not for the two 1991 episodes. To account for the 1991 - 1996 difference, a set of simple"backcast" emission factors were derived by comparing the county-level emissions in the 1991 LMOP inventory (LADCO, 1995) and the 1996 base year inventory[6]. The resulting factors were: elevated NOx x 1.3; low-level NOx x 0.7; and low-level VOC x 1.6. (Note, although these factors were derived primarily based on the county-level emissions for the IL-IN-WI severe nonattainment area, they were applied to the entire domain. To avoid incorrectly increasing biogenic emissions, the low-level VOC factor was applied to all species, except isoprene.)

Spatial Pattern: Peak daily 1-hour modeled ozone concentrations for each episode are provided in Figure 4. A comparison of Figures 3 and 4 shows that the areas of high modeled ozone concentrations correspond with the areas of high measured ozone concentrations (e.g., over Lake Michigan). Also, the regional (rural) modeled and measured ozone concentrations are comparable (i.e., on the order of 70 - 100 ppb). Peak ozone concentrations over Lake Michigan appear to be underestimated on many days.

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6 IL-IN-WI Severe Nonattainment Area Emissions

	1991 LMOP	1996 GridM
Point	420	182
Area	668	549
MotorVeh	721	412
Total	1809	1143
Point	796	596
Area	286	336
MotorVeh	646	976

Backcast Ratios: Elevated NOx = 796/596 = 1.3
Low-level NOx = (286+646)/(336+976) = 0.7
Low-level VOC = 1809/1143 = 1.6

Temporal Pattern: Time series plots of 1-hour modeled and measured ozone concentrations for select sites are provided in Figure 5. As can be seen, the hour-to-hour and day-to-day variation of modeled and measured ozone concentrations are comparable. The magnitude of the modeled concentrations tend to be higher at night and lower during the afternoon (as compared to the measured concentrations). At the sites with high measured concentrations (e.g., Sheboygan and Muskegon), the mid-afternoon modeled ozone concentrations are too low.

Magnitude: Ozone statistics (unpaired peak accuracy, average accuracy of peak, normalized bias, and normalized gross error) are presented in Table 2. The statistics for the Lake Michigan area generally comply with USEPA's recommended values (i.e., unpaired peak accuracy of ±15 - 20%, bias of ±5 - 15%, and gross error of 30 - 35%). The statistics further demonstrate the tendency of the model to underestimate measured ozone concentrations.

Other Factors: The model's response to changes in ozone precursor emissions can be assessed by comparing the difference in measured and modeled ozone concentrations between 1991 and 1996. Observed high ozone concentrations (as represented by design values) have declined on average by about 10 - 20 ppb at many sites between 1991 and 1996. The difference in peak modeled 1-hour ozone concentrations for two episodes with 1996 base year and "backcasted" 1991 emissions is also about 10 - 20 ppb. This cursory assessment indicates that both the model is responsive to changes in ozone precursor emissions, and the simulated change is consistent with observed air quality data.

The effect of grid resolution on model performance can be assessed by comparing the 4 km and 12 km results. The 4 km and 12 km plots of peak daily 1-hour ozone concentrations reflect similar patterns (see Figures 6 and 4). The 4 km and 12 km ozone statistics (see Table 3) are also similar, although the 4 km concentrations tend to be lower than the12 km concentrations. In general, it appears that model performance at 4 km is consistent with that at 12 km.

Based on this information, it is reasonable to conclude that model performance is acceptable and that the model can be used for air quality planning analyses. Efforts to improve the modeling are encouraged (e.g., better model inputs, especially meteorological fields, and better diagnostic tools, such as process analysis). A particular problem is the model's tendency to underestimate peak ozone concentrations. This suggests that the modeled attainment demonstration provides no margin of safety.

Section 5
Strategy Modeling

The purpose of strategy modeling is to evaluate the ozone air quality impact of various control scenarios. For this modeling analysis, the following strategies were modeled:

CAA controls (12 km and 4 km runs)

CAA controls + 0.25 utilities (IL,IN,WI) + 0.25 utilities (KY,MO,TN) + Tier II/Low S (12 km and 4 km runs)

CAA controls + 0.20 utilities (IL,IN,WI) + 0.25 utilities (KY,MO,TN) + Tier II/Low S

CAA controls + 0.20 utilities (IL,IN,WI) + 0.25 utilities (KY,MO,TN) + SIP Call non-utilities (IL,IN,WI) + Tier II/Low S

CAA controls + 0.15 utilities (IL,IN,WI) + 0.25 utilities (KY,MO,TN) + SIP Call non-utilities (IL,IN,WI) + Tier II/Low S

CAA controls + 0.15 utilities + SIP Call non-utilities+ Tier II/Low S (same as SIP Call)

Michigan utilities and non-utilities were modeled at their State rule [e.g., 0.25/65% utilities] in SR8 - SR11, and Indiana non-utilities were modeled at their State rule in SR10 - SR11. The emissions for these scenarios are summarized in Table 1 and Figure 7. The control measures considered in these runs are summarized in Table 4. The strategy runs all assumed CAA boundary conditions (i.e., sources outside of the Grid M modeling domain reflect only CAA controls).

In addition, the following sensitivity runs were modeled:

SR1a CAA controls + Tier II/Low S (12 km and 4 km runs)
SR1b CAA controls w/ boundary conditions based on 0.25 utilities
SR1c CAA controls w/ boundary conditions based on SIP Call (utilities and non-utilities)

SR8a SR8 + 0.25 utilities (IA)
SR8b SR8 w/ -25% VOC reduction (Lake Michigan area)

SR12a SR12 w/ -25% utility NOx reduction
SR12b SR12 w/ -25% VOC reduction (Lake Michigan area)

Following the completion of these runs, several changes to the emissions were identified and five additional strategy runs (SR13 - SR17) were performed. SR13 and SR15 reflect a "0.25 utility" control scenario (similar to SR8), while SR14, SR16, and SR17 reflect a "0.15 utility" control scenario (similar to SR12). The additional runs incorporate the following changes relative to SR8 and SR12:

0.25 SCENARIO

SR8

Point Sources:	IL, IN, MI, WI, KY, MO, TN EGUs @ 0.25
	MI nonEGU @ state rule
Motor Vehicle:	Tier II/Low S

SR13 Changes

Point Sources:	TVA sources @ 0.15
	(Paradise 1-3; Allen 1-3; Cumberland 1-2; Kingston Stacks 1 and 2)
	New ROG controls in IL (ERMS rule)
	IN non-utility sources @ proposed State rule
	WI @ proposed State rule
	MO @ State rule
Motor Vehicle:	Increased VMT growth scenario for SE WI (high plus 7%)
	Proposed diesel sulfur rule (-0.1%)
Low-Level Emissions:	Reduce CO emissions by 12.5% (due to Low S and nonroad controls)
Boundary Conditions:	New point source file (W MO @ 0.35, OTC States @
(CAA12 file)	SIP Call, TVA sources in AL, TN @ 0.15, Texas sources reduced by 50%)
	Reduce low-level NOx emissions by 6.5% (due to Tier II/Low S and nonroad controls)

Note: except for these specific changes, the boundary conditions reflect CAA controls

SR15 Changes

Point Sources:	WI @ revised state rule
Motor Vehicle:	WI with NOx I/M cut-points
(base12v4)	Revised CATS network data
	Updated MOBILE5 inputs for IL, WI
	Corrected MOBILE5 inputs for OH

0.15 SCENARIO

SR12

Point Sources:	EGUs @ 0.15 (SIP Call)
	NonEGUs @ SIP Call
Motor Vehicle:	Tier II/Low S

SR14 Changes

Point Sources:	TVA sources @ 0.15
	(Paradise 1-3; Allen 1-3; Cumberland 1-2; Kingston Stacks 1 and 2)
	New ROG controls in IL (ERMS rule)
	WI @ proposed State rule
	MO @ State rule
	IC engines @ CAA
Motor Vehicle:	Increased VMT growth scenario for SE WI (high plus 7%)
	Proposed diesel sulfur rule (-0.1%)
Low-Level Emissions:	Reduce CO emissions by 12.5% (due to Low S and nonroad controls)
Boundary Conditions:	New point source file (W MO @ 0.35, OTC States @
(CAA12 file)	SIP Call, TVA sources in AL, TN @ 0.15, Texas sources reduced by 50%)
	Reduce low-level NOx emissions by 6.5% (due to Tier II/Low S and nonroad controls)

Note: except for these specific changes, the boundary conditions reflect CAA controls

SR16 Changes	
Point Sources:	WI @ revised state rule
Motor Vehicle:	WI with NOx I/M cut-points
(base12v4)	Revised CATS network data
	Updated MOBILE5 inputs for IL, WI
	Corrected MOBILE5 inputs for OH

SR17 Changes	
Point Sources:	WI @ revised state rule
	Eastern MO EGU and nonEGU @ SIP Call
Motor Vehicle:	WI with NOx I/M cut-points
(base12v4)	Revised CATS network data
	Updated MOBILE5 inputs for IL, WI
	Corrected MOBILE5 inputs for OH

The results for the strategy and sensitivity runs are summarized below.

Effect of CAA Controls:
The net effect of growth and CAA control is a reduction in VOC emissions of about 2100 tons per day and in NOx emissions of about 2400 tons per day compared to the 1996 base year emissions. The change in ozone concentrations between SR1 and 96bas is shown in Figure 8. The peak daily 1-hour ozone concentrations for SR1 are shown in Figure 9. As can be seen, there are widespread ozone decreases and isolated increases. The ozone decreases occur in areas with high 1996 base year ozone concentrations (i.e., ozone benefits occur where it counts).

Effect of Tier II/Low S:
Tier II/Low S controls provide a reduction in VOC emissions of about 200 tons per day and in NOx emissions of about 700 tons per day compared to the Clean Air Act (SR1) control level.[7] Table 5 presents the peak 1-hour ozone concentrations, the number of grid cells > 124 ppb, and the number of hours > 124 ppb in the Lake Michigan area for SR1a and SR1 at both 12 and 4 km resolution. These results show that Tier II/Low S controls will have a small, generally positive effect on reducing ozone levels in the Lake Michigan area. For example, the peak 1-hour ozone concentrations decrease by about 1 - 2 ppb on many days, the number of grid cells > 124 ppb decrease by about 10 - 50%, and the number of

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In the previous inventory (95bas11v2), across-the-board control factors (4% for VOC and 18% for NOx) were applied to the motor vehicle emissions based on USEPA, 1999a. In the new inventory (base12), the new Tier II/Low S control factors were derived based on the "multiplicative adjustment factors" (MAFs) identified in USEPA, 1999b. These MAF's reflect the difference between MOBILE5 and MOBILE6, the effect of air conditioner usage, and the effect of the proposed Tier II/Low S program. For now, only the Tier II/Low S effects are included in the modeling analysis. (This will be done by calculating ratios of the 2007 baseline and 2007 control MAF's.)

hours > 124 ppb decrease by 20 - 50%[8]. The 12 and 4 km results are similar. The only metric reflecting an increase is the peak 1-hour ozone concentration for two days from the July 1995 episode (i.e., July 11 for 12 km results, and July 18 for 4 km results). It should be noted, however, that the increase is only 1 - 2 ppb and occurs on low ozone days.

Figure 10 shows three versions of the change in daily peak 1-hour ozone concentrations for the July 1995 episode: (a) 4 km @ ± 18 ppb, (b) 12 km @ ± 18 ppb, and (c) 12 km @ ± 9 ppb[9]. Comparing the plots across the top and middle of the figure indicates relatively little difference between the 12 and 4 km results. Comparing the plots across the middle and bottom of the figure indicates similarities in the spatial pattern of concentration changes, although there is better resolution with the finer concentration scale. Given these findings, a plot of the 12 km results @ ± 9 ppb was prepared for all four episodes (Figure 11)[10]. Two observations on this plot should be noted:

> Ozone decreases on the order of 1 - 3 ppb occur over large areas on many days. The spatial coverage of the decreases are greatest on the higher ozone days during each episode (e.g., June 26, 1991; July 20, 1991; June 24, 1995; and July 13-14, 1995) and include the major urban areas (e.g., Chicago, St. Louis, Detroit, and Indianapolis). Thus, ozone benefits occur when and where it counts.
>
> Ozone increases occur on a few days in the major urban areas. The increases are generally less than 6 ppb and occur on low ozone days either at the beginning or the end of an episode (i.e., peak 1-hour ozone concentrations less than 100 ppb). As such, the resultant concentrations on these days in these urban areas are still below the 1-hour standard.

In summary, Tier II/Low S controls are beneficial, reducing peak 1-hour ozone concentrations in the Lake Michigan area by 1 - 2 ppb. These reductions, along with reductions from regional NOx controls, will help provide for attainment of the 1-hour ozone

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8 The model results reflect ozone air quality in 2007, which is early-on in the Tier II program. The Tier II standards will be phased in beginning in 2004, with full compliance for new passenger cars and light LDTs by 2007 and for heavy LDTs and MPDVs by 2009. Fleet turnover will require several more years before the full emission reduction benefits of the program are realized. (The Low S controls are to be fully in place by 2006.)

9 The concentration difference plots are arranged as follows: 12 plots across the top reflect 4 km @ ± 18 ppb; 12 plots in the middle reflect 12 km @ ± 18 ppb; and the 12 plots across the bottom reflect 12 km @ ± 9 ppb.

10 The concentration difference plots are arranged as follows: six plots in upper left hand corner are six days in the June 1991 episode; six plots in the upper right hand corner are six days in the July 1991 episode; 12 plots across the middle are 12 days in the June 1995 episode; and 12 plots across the bottom are 12 days in the July 1995 episode.

standard in the Lake Michigan area. Benefits in other areas in the Midwest (e.g., St. Louis Detroit, and Indianapolis) are also apparent.

Effect of Regional NOx Controls:
Figure 12 shows the change in ozone concentrations resulting from reducing utility emissions in IL, IN, MI, WI, KY, MO, and TN from the CAA to a 0.25 lb/MMBTU control level. The peak daily 1-hour ozone concentrations for SR8 are shown in Figure 13. These controls represent a reduction in NOx emissions of about 2000 tons per day compared to the Clean Air Act control level. Two observations on these plots should be noted:

> Ozone decreases on the order of 2 - 6 ppb (or more) occur over large areas on many days. The spatial coverage of the decreases are greatest on the higher ozone days during each episode (e.g., June 26, 1991; July 20, 1991; June 24, 1995; and July 12-14, 1995) and include the areas of highest modeled concentrations. Thus, ozone benefits occur when and where it counts.
>
> Ozone increases occur on a few days in spotty areas. The increases are generally no more than 2 - 6 ppb and occur on low ozone days either at the beginning or the end of an episode (i.e., peak 1-hour ozone concentrations less than 100 ppb). As such, the resultant concentrations on these days in these areas are still below the 1-hour standard.

The peak daily 1-hour ozone concentrations for SR15 are shown in Figure 14. The results for SR13 and SR15 are similar to those for SR8, but produce slightly different attainment statistics, as discussed below.

Figure 15 shows the change in ozone concentrations resulting from 0.25 utility controls based on 4 km model runs. Compared to Figure 12, Figure 15 shows similar areas of ozone decreases and increases. Thus, the effect of grid resolution does not seem to change the general model results.

Figure 16 shows the change in ozone concentrations resulting from reducing utility emissions in IL, IN, and WI from a 0.25 lb/MMBTU to a 0.20 lb/MMBTU control level. These controls represent a reduction in NOx emissions of about 200 tons per day compared to the Clean Air Act control level. As can be seen, this relatively small emission reduction results in relatively small ozone changes (decreases).

Figure 17 shows the change in ozone concentrations resulting from reducing utility emissions in IL, IN, and WI from a 0.20 lb/MMBTU to a 0.15 lb/MMBTU control level. These controls represent a reduction in NOx emissions of about 200 tons per day compared to the Clean Air Act control level. As can be seen, this relatively small emission reduction results in relatively small ozone changes (decreases).

Figure 18 shows the change in ozone concentrations resulting from reducing nonutility emissions in IL, IN, and WI from the CAA to the SIP Call control level. These controls represent a reduction in NOx emissions of about 90 tons per day compared to the Clean Air Act control level. As can be seen, this relatively small emission reduction results in relatively small ozone changes (decreases).

Figure 19 shows the change in ozone concentrations resulting from reducing both utility emissions in Grid M from a 0.25 lb/MMBTU control level to a 0.15 (SIP Call) control level, and nonutillity emissions from the CAA to the SIP Call control level. The peak daily 1-hour ozone concentrations for SR12 are shown in Figure 20. The SIP Call controls represent a reduction in NOx emissions of about 1600 tons per day compared to SR8. As can be seen, there some areas with ozone decreases and a few spotty areas with ozone increases. (Note, the results for SR14, SR16, and SR17 are similar to those for SR12, but produce slightly different attainment statistics, as discussed below.)

Effect of Other Controls: The sensitivity runs provide information about three additional control scenarios: Iowa utilities at 0.25 lb/MMBTU (SR8a); an additional 25% reduction in utility NOx emissions beyond the SIP Call (SR12a); and an additional 25% reduction in VOC emissions in the Lake Michigan area beyond the SIP Call (SR12b). In addition, SR1b and SR1c address the effect of boundary conditions. The results of these runs are summarized below.

Figure 21 shows the change in ozone concentrations resulting from controlling just Iowa utilities to 0.25 lb/MMBTU. These controls represent a reduction in Iowa utility NOx emissions of about 45 tons per day compared to the Clean Air Act control level. As can be seen, most of the reduction in ozone concentrations occurs in or immediately downwind of Iowa; there is relatively little effect in the Lake Michigan area on most days.

Figure 22 shows the change in ozone concentrations resulting from an additional 25% reduction in utility NOx emissions beyond the SIP Call. These controls represent a reduction in elevated point source emissions of about 470 tons per day compared to the SIP Call control level. As can be seen, there are some areas with ozone decreases.

Figure 23 shows the change in ozone concentrations resulting from an additional 25% reduction in VOC emissions in the Lake Michigan area beyond the SIP Call. These controls represent a reduction in VOC emissions of about 300 tons per day compared to the SIP Call control level. As can be seen, there are some areas with ozone decreases. Although limited in spatial extent, these decreases will provide benefits in highly populated areas which generally have high local ozone concentrations.

Figures 24 and 25 show the effect of 0.25 and SIP Call boundary conditions, respectively. As can be seen, assuming additional upwind controls will result in some slight reduction in peak 1-hour ozone concentrations in the Lake Michigan area on some days.

Section 6
Attainment Demonstration

The purpose of this section is to review the application of USEPA's June 1996 1-hour attainment tests (USEPA, 1996). To supplement these modeling results, two additional analyses are presented: USEPA's draft May 1999 attainment test (USEPA, 1999c) and air quality analyses.

The June 1996 guidance allows two tests: a deterministic test and a statistical test. The deterministic test is a conservative, simple means of assessing attainment. The statistical test is intended to make the modeled attainment test more closely reflect the form of the 1-hour NAAQS. This is done by considering the severity of selected episode days more explicitly and allowing modeled exceedances on severe days, and by considering the uncertainty inherent in modeling analyses and allowing use of supplementary information to determine whether attainment is likely (i.e., a weight-of-evidence determination).

The May 1999 guidance specifies a relative test which uses monitored design values in concert with model-generated data. The primary advantages of this test over other tests are its use of observed design values to "anchor" model predictions to the form of the NAAQS, and its more explicit recognition of model uncertainty by relying on "relative", not "absolute" model results.

Two air quality analyses were performed: trends in ozone and ozone precursor concentrations, and application of observation-based methods. Trends analyses provide information about progress toward attainment and the relative effectiveness of control programs. Observation-based methods provide information about the relative effectiveness of VOC v. NOx control.

USEPA recommended that the attainment tests be applied to those days with acceptable model performance. By dealing with model performance up-front, issues concerning model underprediction and overprediction become less of a factor in reviewing the results of the tests (i.e., avoids unnecessary weight-of-evidence arguments). Based on the performance results presented in Section 4, the following 18 days were determined to be appropriate for applying the attainment tests:

June	25 - 28	1991
July	16 - 20	1991
June	21 - 25	1995
July	12 - 15	1995

Deterministic Approach (June 1996 Guidance)
The deterministic test is passed if the daily maximum concentrations predicted in each surface grid cell are < 125 ppb for all primary episode days. If there are only a few modeled exceedances (e.g., 2 - 3 grid cells ≥ 125 ppb), then this approach may still be used to demonstrate attainment by including a weight of evidence determination.

The daily maximum concentrations in the Lake Michigan area for the 96base and each strategy scenario are presented in Table 6. The number of days with maximum concentrations ≥ 125 ppb are as follows:

SR1	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17
8	5	5	5	5	5	4	4	5	4	4

These results show that the deterministic test is not met by any of the strategies. It should be noted that all of the modeled exceedance days for SR8 - SR12 are considered "severe" based on the USEPA's (Cox-Chu) ranking scheme. Although severity can be considered in this test as part of a "weight-of-evidence" determination, it is dealt with more directly in the statistical test below.

Statistical Approach (June 1996 Guidance)
The statistical approach permits occasional exceedances and reflects an approach comparable to the form of the 1-hour NAAQS. This flexibility is important given uncertainties in the modeling and the severity of the modeled episodes. The statistical approach includes three benchmarks related to the frequency and magnitude of allowed exceedances and the minimum level of improvement. The statistical approach test is passed if all three benchmarks are met, or if one or more benchmarks is not met, then a weight of evidence determination is provided. The benchmarks are addressed below.

Benchmark 1. Limits on Number of Modeled Exceedance Days
This benchmark requires both that the number of days with modeled exceedances in each 12 km grid cell must be less than 3 or "N - 1", whichever is less ("N" is number of "severe" days), and that any modeled exceedance occurs on a severe day. A day is "severe" if its "meteorological ozone forming potential" (based on the Cox-Chu ranking scheme) is expected to be exceeded less than twice per year (i.e., ExEx value < 2). These days have a Cox-Chu ranking or 87 or less (based on a 45-year period of data: 1951 - 1995). The following modeling days are severe:

Jul 18,1991 (#9 Milw) Jun 19,1995 (#49 Milw) Jul 12,1995 (#31 Milw, #62 Musk, #59 Chi)
Jul 19,1991 (#67 Chi) Jun 22,1995 (#32 Chi) Jul 13,1995 (#19 Milw, #12 Musk)
Jul 20,1991 (#78 Musk) Jun 24,1995 (#10 Chi) Jul 14,1995 (#48 Milw, #5 Musk)
Jul 15,1995 (#16 Chi)

Thus, the number of allowed exceedances is 3.

The maximum number of exceedance days in any subregion is as follows

SR1	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17
3	2	2	1	1	1	1	1	1	1	

Thus, there are no more than 3 exceedances in any grid cell. Furthermore, for each strategy except SR1, the only modeled exceedances are on severe days (Jul 20, 1991; Jun 22, 24, 1995; and Jul 13 - 15, 1995). For SR1, there are exceedances on two non-severe days (Jun 26, 1991; and Jun 23, 1995).

Benchmark 2. Limits on Value of Allowed Exceedances
The maximum modeled concentration shall not exceed 130 ppb on days with an ExEx rate between 0.5 and 2.0/year (i.e., ranking of 22 - 90), and a slightly higher value (see Table 4.2 of the June 1996 guidance) on days with an ExEx rate less than 0.5/year (i.e., ranking less than 22).

The daily peak 1-hour concentration for each severe and modeled exceedance day are presented in Table 7. The number of days with modeled concentrations greater than the allowed value are as follows:

SR1	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17
5	1	1	1	1	0	0	0	0	0	0

Benchmark 3. Required Minimum Level of Improvement
The number of grid cells $\geq$ 125 ppb must be reduced by 80% on each severe day. This benchmark is included to provide protection in cases where the model underpredicts observed ozone concentrations; it is not required on days when the model does not underpredict by more that 5%.

The degree of improvement for each severe and modeled exceedance day are presented in Table 7. The number of days the 80% criteria is not met are as follows:

SR1	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17
6	0	0	0	0	0	0	0	0	0	0

These results indicate that: (1) SR1, which does not pass any of the benchmarks, is not sufficient to provide for attainment; (2) SR8 - SR11 come close to showing attainment, but appear to fall just short (i.e., only Benchmark 2 is failed and the failure is by only 1 - 2 ppb on July 20, 1991, a day with model overprediction); and (3) SR12 - 17, which meet all three benchmarks, are sufficient to provide for attainment.

Weight of Evidence
To supplement the model-based attainment tests, two additional analyses are provided: a relative attainment test and air quality data analyses. These two analyses are discussed separately below.

Relative Attainment Test: The relative attainment test uses observation-based design values in concert with modeling data. The observed design value is multiplied by the change in ozone concentrations between the 1996 base yer and a given strategy (i.e., the relative reduction factor or RRF). To show attainment, the adjusted design value must be below the ozone NAAQS.

Because the variability in meteorological conditions can heavily influence the observation-based design values, USEPA recommends two approaches for selecting the design values: (1) higher of the design value for either the 3-year period "straddling" the inventory base year (1995-1997) or the most 3-year period (1997-1999); and (2) the average of the design values for the three 3-year periods which include the inventory base year (1994-1996, 1995-1997, and 1996-1998). The latter approach was assumed here.

The observation-based design values for those sites with a measured "violation" anytime during the past five 3-year periods are as follows:

Site	'93-'95	'94-'96	'95-'97	'96-'98	'97-'99
Wisconsin					
Pleasant Prairie	127	129	129	136	126
Racine	113	119	119	129	117
South Milwaukee	120	121	126	117	117
Bayside	128	128	126	129	129
Grafton	112	121	122	123	128
Harrington Beach	126	126	126	129	134
Sheboygan	114	122	123	130	132
Manitowoc	122	126	126	128	128
Newport Beach	121	125	127	116	115
Indiana					
Michigan City	131	146	146	128	121
Michigan					
Muskegon	141	142	136	121	115
Holland	135	137	137	123	123
Grand Rapids	114	127	124	104	99
Coloma	115	116	119	125	119

The resulting design values to be used in the relative attainment test (based on the average of the three 3-year periods including the inventory base year) are as follows:

SITE	AVERAGE OF '94-'96,'95-'97,'96-'98
Pleasant Prairie	131
Racine	122
South Milwaukee	121
Bayside	128
Grafton	122
Harrington Beach	127
Sheboygan	125
Manitowoc	127
Newport Beach	123
Michigan City	140
Muskegon	133
Holland	132
Grand Rapids	118
Coloma	120

USEPA's guidance includes an additional "improvement" requirement for unmonitored areas with substantially higher modeled ozone concentrations than in the vicinity of any monitor (e.g., over Lake Michigan). Specifically, the RRF for these high modeled, unmonitored areas multiplied by the area-wide maximum observed design value must be less than the NAAQS. In other words, the improvement at these locations must be as much that needed to bring the highest monitoring site into attainment. To address this requirement, a "phantom" monitor over Lake Michigan was included in the analysis.

The RRF is calculated based on the ratio of the average daily peak "nearby" 1-hour concentrations for the 1996 base year and a given strategy. USEPA's guidance recognizes that on a given modeled day, meteorological conditions may not be similar to those leading to high concentrations at a particular monitoring site. If ozone concentrations predicted near a monitor on a given day are very much less than the design value, then the model predictions could be unresponsive to controls and result in an erroneously high projection of the future year design value. To address this concern, only those days with "high" base year concentrations (≥100 ppb) in each of four general areas (i.e., Wisconsin, Indiana, Michigan, and over Lake Michigan) were used to calculate the RRF for those areas. The days are shown in Figure 26. The resulting model-adjusted future year 1-hour design values are as follows:

SITE	Obs. D.V.	SR1	SR8	SR13	SR14	SR15	SR16	SR17
Pleasant Prairie	**131**	**126**	116	115	114	114	113	113
Milwaukee-Bayside	**128**	123	116	115	114	114	113	113
Harrington Beach	**127**	123	113	112	111	112	110	109
Sheboygan	**125**	121	112	111	110	110	108	108
Manitowoc	**127**	121	112	111	109	110	108	108
Michigan City	**140**	132	125	124	121	122	119	119

SITE	Obs. D.V.	SR1	SR8	SR13	SR14	SR15	SR16	SR17
Holland	133	127	121	120	118	119	117	117
Muskegon	132	126	120	118	117	118	117	117
Unmonitored(mid-Lake)	140	132	126	124	123	124	122	122

These results are consistent with those of the statistical attainment test.

Preliminary 8-hour results for a few strategies based on all modeling days (not just the select days identified in Figure 26) are presented in Table 8.

Air Quality Analyses: To supplement the photochemical modeling, two air quality analyses were considered: analysis of air quality trends and application of observation-based methods. These analyses, which are recommended by USEPA in the May 1999 draft guidance as core analyses for a weight-of-evidence determination, provide further information to support the attainment demonstration. In particular, the analyses corroborate the conclusions of the model analysis and support the general direction of the control strategies in the modeling

<u>Trends</u>**:** Examination of the changes in ozone air quality over time provides information about progress toward attainment and the relative effectiveness of control programs. The trends in local ozone concentrations, local ozone precursor concentrations, and incoming ozone concentrations are discussed below.

Ozone Exceedance Metrics: The number of exceedance days and the number of exceedance site days are shown in Figure 27(a); and the number of hot days and number of cooling degree days in Figure 27(b). The figures show:

> The number of exceedance days in the 1980's (i.e., 207) is much more than those in the 1990's (i.e., 89); whereas the number of hot days in the 1980's (i.e., 194) is only slightly more than those in the 1990's (i.e., 162).
>
> During most years in the 1980's, there were more exceedance days than hot days; whereas during most years in the 1990's there were more hot days than exceedance days.
>
> The number of exceedance days and site exceedance days is generally higher during the hotter summers. In comparison to prior hot summers, there were substantially fewer exceedance days and site exceedance days during 1998 and 1999.

The high design values for 1987 - 1989 and 1997 - 1999 are shown in Figure 28. As seen in this figure, the spatial extent and magnitude of ozone violations has decreased considerably over the past 10 years.

Meteorology-Adjusted Ozone Trends: Given the strong effect of meteorology on ambient levels, year-to-year variations in meteorology can make it difficult to assess trends in ozone air quality. Three statistical methods were used to adjust ozone trends for meteorological influences. Application of the Rao-Zurbenko method for data from the period 1980 - 1995 found that daily peak 1-hour ozone levels at most sites decreased until the mid-1990's and then leveled-off (or slightly increased) (WDNR, 1997; WDNR, 2000). Application of the Cox-Chu method for data from the period 1989 - 1998 found that similar ozone trends at sites in Chicago, Milwaukee, and Muskegon (Cox, 1999). A plot of the meteorology-adjusted ozone levels for three sites using these two methods is presented in Figure 29. Application of a simple regression model based on ozone and temperature showed a statistically significant downward trend at two sites in southeast Wisconsin, a statistically significant upward trend at a far downwind site (Door County, Wisconsin), and a statistically insignificant trend elsewhere (Rizzo, 2000).

Ozone Precursor Trends: Local surface ozone precursor data are extremely limited. There is only one site (UWM-North site in Milwaukee, Wisconsin) with as much as 10 years of ozone precursor data. These data indicate that NMHC and, to a much lesser degree, NOx concentrations have declined since the mid-1980's (see Figure 30(a)). The decrease in NMHC concentrations is associated with (and perhaps explains) the decrease in local ozone concentrations (see Figure 30(b)). The Lake Michigan regional Photochemical Assessment Monitoring Stations (PAMS) began operation in the mid-1990's and, eventually, should provide a reliable data base for assessing ozone precursor trends.

Background Trends: Upwind air quality data also extremely limited. The mean incoming (regional) ozone levels since 1980 were estimated based on surface measurements collected in an area approximately 50 miles SW of Chicago. The incoming ozone levels have remained fairly steady over the past 20 years (i.e., mean concentrations of about 60 ppb throughout the summer and about 70 - 90 ppb on high ozone days). These levels are about 40 - 60% of the local peak 1-hour ozone concentrations in the Lake Michigan area.

<u>Observation-Based Methods:</u> Observation-based methods provide information about the relative effectiveness of VOC v. NOx control. Advantages of these analyses are their reliance on measured data, and the ability to consider a wide range of conditions, not just modeled days. A summary of three observation-based methods is presented below.

MAPPER: This program uses measurements of ozone, NO, and NOy (or NOx) with the Smog Production Algorithm to estimate the "extent" of photochemical reaction. VOC- and NOx-limited conditions are defined based on the extent parameter during periods of high ozone: < 0.6, VOC-limited; > 0.9, NOx-limited; 0.6 < and < 0.9, transition (Blanchard et al, 1994). Three applications of MAPPER were considered:

> Data from three episodes from the 1991 LMOS field program show VOC-limited conditions in the major urban areas, NOx-limited conditions at

downwind sites during hours with high ozone concentrations, and the transition from VOC-limited to NOx-limited conditions occurs about 50 - 100 km downwind of Chicago (STI, 1995).

PAMS data in the Lake Michigan area from 1996 - 1998 show VOC-limited conditions at urban (Type 2) sites, and transition or NOx-limited conditions at downwind (Type 3 and 4) sites during high ozone hours (USEPA, 1999d).

* Data from the four subregional modeling episodes show VOC-limited conditions in the Chicago and Milwaukee urban areas and NOx-limited conditions at downwind sites during hours with high ozone concentrations (see, for example, the results for July 1995 in Figure 31). Furthermore, the results show that the air becomes more NOx-limited over the course of an episode (WDNR, 1999).

Control Curves: A simple box model was applied with source emission estimates of VOC and NOx from receptor modeling to generate VOC-ozone and NOx-ozone "control" curves. Data from the two 1991 episodes and the summer of 1995 were used (Chung, et al, 1996, and Chung, 2000). An example plot of the control curves for select locations in the Lake Michigan area is provided in Figure 32(a). Consideration of the results over all days indicates VOC-limited conditions in Chicago, Gary, and Milwaukee; and NOx-limited conditions over the Lake and downwind in northeastern Wisconsin and western Michigan. In addition, the relationship between ozone response to NOx reductions and ozone concentration shows ozone increases only at lower ozone levels and ozone decreases at higher ozone levels (>100 ppb) - see Figure 32(b).

Indicator Species: A review of several modeling studies found that certain "indicator" species or ratios of species can be used to distinguish between VOC- and NOx-limited conditions: NOy, NOz, O3/NOy, O3/NOz, O3/HNO3, H2O2/HNO3, and H2O2/NOz (Milford et al, 1994, and Sillman et al, 1997). Unfortunately, measurements of many of these species are generally not available (e.g., only ozone and a limited amount of NOy [or NOx] data exist in the Lake Michigan area). The O3/NOy ratio[11] for a typical high ozone day (see Figure 33) indicates:

The air entering the region is NOx-limited, as seen by the relatively high ratios (>20) for the morning ("A") boundary flight.

The plumes coming out of the Chicago, Gary, and Milwaukee urban areas in the morning are VOC-limited, as seen by the relatively low ratios (<5) for the morning ("B") over-Lake flight.

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[11] The critical O3/NOy ratio is about 6.0 - 7.5 (i.e., values less than this indicate VOC-limited conditions, and values greater than this indicate NOx-limited conditions).

The ratios are higher for the second afternoon flight ("D") compared to the first afternoon flight ("C"), and also higher on each subsequent episode day, indicating additional photochemical activity (and NOx consumption). This suggests that the air over the Lake becomes more NOx-limited over the course of a day and over the course of an episode.

In summary, the trends analyses show that there has been considerable progress toward attainment of the 1-hour NAAQS in the Lake Michigan area. Local ozone levels have declined in recent years, but incoming (regional) levels remain high. The reduction in local ozone levels can be attributed to local VOC control programs, as evidenced by the decline in ambient VOC concentrations and the VOC-limited conditions in the severe nonattainment area. To reduce regional ozone levels, the observation-based methods indicate that regional NOx controls will be effective. Thus, a strategy of additional local VOC controls and regional NOx controls, which is consistent with the modeling, will be effective ozone concentrations in the Lake Michigan area.

Section 7
Summary

A state-of-the-art modeling analysis was performed to support the updated 1-hour ozone attainment for the Lake Michigan area. The results of the analysis are considered to be technically credible. In particular, model performance was determined to be reasonable (i.e., there is good agreement in the magnitude, spatial pattern, and temporal profile of modeled and measured ozone concentrations) and the response of the model to changes in emissions was found to be consistent with previous modeling and corroborative air quality analyses. The model can, therefore, be used to support regulatory applications for the Lake Michigan area.

Based on the modeling analysis, the following strategy-relevant findings can be made:

Domainwide (principally, urban area) VOC emission reductions decrease ozone concentrations in urban nonattainment areas. The spatial extent of the ozone decreases is limited, but do occur in high population and generally high ozone areas.

* Domainwide NOx emission reductions decrease ozone concentrations, but can sometimes increase ozone concentrations. Ozone decreases occur throughout much of the modeling domain, including areas with high base year concentrations. Ozone increases are limited mostly to urban areas and are most pronounced on days with lower 1-hour concentrations.

The modeled attainment tests show that Clean Air Act controls alone will reduce ozone concentrations, but do not, by themselves, provide for attainment of the 1-hour NAAQS everywhere in the Lake Michigan area. The full set of controls (i.e., Clean Air Act controls; State ROP emission reductions; Tier II/Low S program; and a range of regional point source NOx controls, as reflected by Strategy Runs 12 - 17) provide for attainment of the 1-hour NAAQS throughout the Lake Michigan area.

Section 8
References

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Table 6. Results of Deterministic Attainment Test

<u>Test</u>: Pass if daily max ozone in every surface grid cell for all days ≤ 124 ppb

<u>Results</u>:

	96bas	SR1	SR1a	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17
6-25-91	123	116	114	113	113	113	113	113	111	110	111	110	110
6-26-91	**138**	**126**	124	122	122	121	121	119	120	117	120	117	117
6-27-91	**127**	118	117	114	114	114	114	113	112	111	112	111	111
6-28-91	102	98	97	95	95	95	95	95	93	93	96	95	95
7-16-91	108	104	104	104	104	103	103	103	104	103	104	103	103
7-17-91	89	88	88	88	89	89	90	90	87	88	89	89	89
7-18-91	108	106	106	107	106	107	106	107	104	104	109	109	109
7-19-91	112	113	112	111	111	111	111	110	110	110	112	111	111
7-20-91	**150**	**138**	**136**	**132**	**131**	**131**	**131**	**130**	**130**	**129**	**130**	**128**	**128**
6-21-95	122	122	120	120	120	120	120	120	118	118	118	118	118
6-22-95	**131**	**131**	**130**	124	124	124	124	121	122	119	122	119	119
6-23-95	**128**	**125**	124	119	119	119	119	116	116	113	116	113	113
6-24-95	**136**	**128**	**126**	**127**	**127**	**128**	**128**	**127**	123	123	**126**	**126**	**126**
6-25-95	124	120	120	121	121	122	122	122	119	119	120	120	120
7-12-95	118	107	106	104	104	104	104	103	104	103	105	105	104
7-13-95	**146**	**131**	**130**	**128**	**129**	**128**	**128**	**128**	**127**	**126**	**125**	124	124
7-14-95	**140**	**130**	**129**	**128**	**129**	**128**	**128**	**128**	**126**	126	**127**	**127**	**127**
7-15-95	**156**	**136**	**135**	**135**	**135**	**135**	**135**	**135**	**130**	**130**	**129**	**128**	**128**

Table 7. Results of Statistical Attainment Test

Test: Pass if meet three benchmarks. If fail one or more benchmarks, then may still pass dependin on WOE determination

Benchmark 1 (Limit on number of modeled exceedances)

Requirements

Number of days with allowed exceedances in each subregion is 3 or ≤ "N" - 1 ("N" = number of sever days), whichever is less

Exceedances allowed only on "severe" days[12]

Results

Maximum number of exceedances

SR1	SR1a	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17
3	3	2	2	1	1	1	1	1	1	1	1

Exceedance days

SR1:	8	**6-26-91**	7-20-91	6-22,**23**,24-95	7-13,14,15-95
SR1a:	6		7-20-91	6-22,24-95	7-13,14,15-95
SR8-12:	5		7-20-91	6-24-95	7-13,14,15-95
SR13,14:	4		7-20-91		7-13,14,15-95

*(Note: non-severe days shown in **red** above)*

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12 Severe days = Jul 18 - 20, 1991; Jun 19, 22, 24, 1995; Jul 12 - 15, 1995

Benchmark 2 (Limit on value of modeled exceedances)

Requirement

Modeled concentrations on severe days < 130 - 145 ppb

Results

	Rank	Allowed Value	SR1	SR1a	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	S[illegible]
6-25-91			116	114	113	113	113	113	113	111	110	111	110	1[illegible]
6-26-91			**126**	124	122	122	121	121	119	120	117	120	117	
6-27-91			118	117	114	114	114	114	113	112	111	112	111	1[illegible]
6-28-91			98	97	95	95	95	95	95	93	93	96	95	[illegible]
7-16-91			104	104	104	104	103	103	103	104	103	104	103	1[illegible]
7-17-91			88	88	88	89	89	90	90	87	88	89	89	[illegible]
7-18-91	6	144	106	106	107	106	107	106	107	104	104	109	109	1[illegible]
7-19-91	47	130	113	112	111	111	111	111	110	110	110	112	111	1[illegible]
7-20-91	75	130	**138**	**136**	**132**	**131**	**131**	**131**	130	130	129	130	128	1[illegible]
6-21-95			122	120	120	120	120	120	120	118	118	118	118	1[illegible]
6-22-95	32	130	**131**	130	124	124	124	124	121	122	119	122	119	1[illegible]
6-23-95			**125**	124	119	119	119	119	116	116	113	116	113	1[illegible]
6-24-95	10	139	128	126	127	127	128	128	127	123	123	126	126	1[illegible]
6-25-95			120	120	121	121	122	122	122	119	119	120	120	1[illegible]
7-12-95	31	130	107	106	104	104	104	104	103	104	103	105	105	1[illegible]
7-13-95	12	137	131	130	128	129	128	128	128	127	126	125	124	1[illegible]
7-14-95	5	146	130	129	128	129	128	128	128	126	126	127	127	1[illegible]
7-15-95	16	135	**136**	135	135	135	135	135	135	130	130	129	128	1[illegible]

Benchmark 3 (Required minimum level of improvement)

Requirement

Number of grid cell hours > 124 ppb must be reduced by 80% on severe days
(required only on days > 5% underprediction)

Results

		% Improvement (No. Grid Cell Hours > 124 ppb)											
	Rank	SR1	SR1a	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SF
6-25-91													
6-26-91		87	94	100	100	100	100	100	100	100	100	100	1(
6-27-91		100	100	100	100	100	100	100	100	100	100	100	1(
6-28-91													
7-16-91													
7-17-91													
7-18-91	6												
7-19-91	47												
7-20-91	75	**75**	80	88	89	89	89	91	89	92	92	93	9
6-21-95													
6-22-95	32	**6**	**41**	94	91	91	91	100	100	100	100	100	1(
6-23-95		**67**	83	100	100	100	100	100	100	100	100	100	1(
6-24-95	10	**70**	83	89	89	89	87	89	100	100	96	98	
6-25-95		100	100	100	100	100	100	100	100	100	100	100	1(
7-12-95	31												
7-13-95	12	83	88	94	93	95	95	95	96	97	98	100	1(
7-14-95	5	**77**	82	92	89	91	92	93	98	98	97	98	
7-15-95	16	**74**	80	85	86	88	89	90	97	97	99	99	

'able Emissions Summary (tons per day)

ROG	Point-EGU	Point-NonEGU	Area-Nonroad	Area-Other	Motor Vehicle	Biogenic	Anthropogenic Subtotal	Total
96bas	32	2335	1716	4780	3633	30816	12496	43312
SR1	40	1865	1167	4410	2897	30816	10379	41195
SR8	37	1774	1167	4410	2671	30816	10059	40875
SR9	37	1774	1167	4410	2671	30816	10059	40875
SR10	37	1774	1167	4410	2671	30816	10059	40875
SR11	37	1774	1167	4410	2671	30816	10059	40875
SR12	37	1774	1167	4410	2671	30816	10059	40875
SR13	37	1771	1167	4410	2671	30816	10056	40872
SR14	37	1771	1167	4410	2671	30816	10056	40872
SR15	37	1771	1167	4410	2687	30816	10072	40888
SR16	37	1771	1167	4410	2687	30816	10072	40888
SR17	37	1771	1167	4410	2687	30816	10072	40888
SR1a	40	1865	1167	4410	2671	30816	10153	40969
SR8a	37	1774	1167	4410	2671	30816	10059	40875
SR12a	37	1774	1167	4410	2671	30816	10059	40875
SR12b						30816	9709	40525

NOx	Point-EGU	Point-NonEGU	Area-Nonroad	Area-Other	Motor Vehicle	Biogenic	Anthropogenic Subtotal	Total
96bas	5844	1876	2138	602	5681	2000	16141	18141
SR1	5014	2146	1748	734	4089	2000	13731	15731
SR8	3066	2056	1748	734	3351	2000	10955	12955
SR9	2865	2055	1748	734	3351	2000	10753	12753
SR10	2863	1967	1748	734	3351	2000	10663	12663
SR11	2662	1966	1748	734	3351	2000	10461	12461
SR12	1878	1670	1748	734	3351	2000	9381	11381
SR13	3033	2047	1748	734	3359	2000	10921	12921
SR14	2080	1822	1748	734	3359	2000	9743	11743
SR15	3044	2047	1748	734	3230	2000	10803	12803
SR16	2092	1822	1748	734	3230	2000	9626	11626
SR17	2027	1806	1748	734	3230	2000	9545	11545
SR1a	5014	2146	1748	734	3351	2000	12993	14993
SR8a	3022	2056	1748	734	3351	2000	10911	12911
SR12a	1408	1670	1748	734	3351	2000	8911	10911
SR12b	1878	1670	1748	734	3351	2000	9381	11381

Note, there are two problems with the SR1 emissions: (1) CAA ROG controls were inadvertently omitted in Michigan; point source ROG emissions should actually be less by 90 TPD; and (2) some nonutility NOx emission sources were inadvertenly omitted in Kentucky; point source NOx emissions should actually be greater by 12 tons per day.

Table 2. Model Performance Statistics - Lake Michigan Area (12 km)

	Peak Value obs	Peak Value mod	Unpaired Peak Acc	Ave Acc of Peak	Normalized Bias	Normalize Gross Err
Jun24	92	101	9.8	-20.4	-22.6	23.6
Jun25	104	123	18.3	-16.8	-19.3	22.9
Jun26	175	136	-22.3	11.9	0.5	22.2
Jun27	118	139	17.8	10.8	4.3	17.7
Jun28	138	124	-10.1	-5.3	-12.1	19.0
Jul16	130	129	-0.8		-15.9	19.0
Jul17	137	119	-13.1		-16.8	20.5
Jul18	170	137	-19.4		-2.8	15.9
Jul19	170	137	-19.4		-9.6	20.8
Jul20	139	168	20.9		11.7	20.8
Jul21	101	142	40.6		18.3	27.9
Jun15	125	83	-33.6	-30.4	-33.6	33.7
Jun16	124	97	-21.8	-30.2	-31.9	32
Jun17	145	110	-24.1	-27.7	-29.0	29.3
Jun18	131	109	-16.8	-16	-18.9	20.1
Jun19	118	115	-2.5	-14.6	-18.0	19.5
Jun20	97	120	23.7	-8.2	-18.9	21.4
Jun21	112	123	9.8	-21.2	-23.2	25.9
Jun22	119	131	10.1	-1.7	2.3	16.1
Jun23	123	128	4.1	-11.2	-6.7	17.9
Jun24	166	136	-18.1	-5	-1.6	17.1
Jun25	108	125	15.7	14.4	8.3	16.3
Jul9	122	78	-36.1		-33.3	33.3
Jul10	106	88	-17.0		-30.6	30.6
Jul11	118	88	-25.4		-29.5	29.8
Jul12	146	118	-19.2		-15.2	19.2
Jul13	178	147	-17.4		-14.6	18.9
Jul14	150	140	-6.7		-4.3	14.6
Jul15	154	156	1.3		15.4	22.6
Jul16	92	135	46.7		23.1	25.9
Jul17	88	91	3.4		-33.2	33.3
Jul18	68	55	-19.1		-41.3	41.3
	USEPA Criteria =		**15 - 20%**		**5 - 15%**	**30 - 35%**

Table 3. Model Performance Statistics - Lake Michigan Area (12 v. 4 km)

	Peak Value			Unpaired Pk Acc.		Normalized Bias		Normalized Gross Error	
	obs	uamv (bas12)	uamv (bas12-4km)	uamv (bas12)	uamv (bas12-4km)	uamv (bas12)	uamv (bas12-4km)	uamv (bas12)	uamv (bas12-4km)
Jun24	92	96	100	4.3	8.7	-23.7	-24.4	24.4	24.9
Jun25	104	123	136	18.3	30.8	-20.8	-20.9	24.2	23
Jun26	175	138	135	-21.1	-22.9	-1.4	-3.7	23.2	20.4
Jun27	118	127	121	7.6	2.5	2.7	2.7	17.1	16.3
Jun28	138	102	100	-26.1	-27.5	-15.2	-21.5	21	25.4
Jul16	130	109	106	-16.2	-18.5	-21.9	-29.9	23.2	30.5
Jul17	137	89	88	-35.0	-35.8	-23.7	-31.5	25.6	32.2
Jul18	170	108	102	-36.5	-40.0	-6.9	-16.4	16.5	21.4
Jul19	170	112	107	-34.1	-37.1	-14.3	-24.1	22.1	27.1
Jul20	139	151	136	8.6	-2.2	9.2	-2.3	20.9	18.9
Jul21	101	135	131	33.7	29.7	17.3	11.4	29.0	23.7
Jun15	125	83	82	-33.6	-34.4	-33.6	-34.2	33.7	34.4
Jun16	124	97	93	-21.8	-25.0	-31.9	-35.2	32	35.3
Jun17	145	110	100	-24.1	-31.0	-29.0	-34.3	29.3	34.5
Jun18	131	109	110	-16.8	-16.0	-18.9	-23.2	20.1	24.5
Jun19	118	115	116	-2.5	-1.7	-18.0	-20.6	19.5	22.2
Jun20	97	120	112	23.7	15.5	-18.9	-22.3	21.4	23.4
Jun21	112	123	126	9.8	12.5	-23.2	-26.8	25.9	29.3
Jun22	119	131	132	10.1	10.9	2.3	-3	16.1	16.7
Jun23	123	128	118	4.1	-4.1	-6.7	-10.6	17.9	20.6
Jun24	166	136	133	-18.1	-19.9	-1.6	-7.4	17.1	19.8
Jun25	108	125	126	15.7	16.7	8.3	4.9	16.3	15.8
Jul9	122	78				-33.3		33.3	
Jul10	106	88				-30.6		30.6	
Jul11	118	88				-29.5		29.8	
Jul12	146	118				-15.2		19.2	
Jul13	178	147				-14.6		18.9	
Jul14	150	140				-4.3		14.6	
Jul15	154	156				15.4		22.6	
Jul16	92	135				23.1		25.9	
Jul17	88	91				-33.2		33.3	
Jul18	68	55				-41.3		41.3	

(Note: Jun 91 and Jul 91 results reflect 96bas emissions, not the "backcasted" 91bas emissions.)

Table 4. Control Measures

NOx RUN	UTILITY	NONUTILITY	NONROAD/OTHER AREA	MOTOR VEHICLE
96bas	* Title IV controls (Phase 1)	* RACT at major sources in non-waiver areas	* Fed RFG - Phase I[1]	* Fed RFG - Phase 1[1] * Enhanced I/M[1] * Basic I/M[1]
SR1	* Title IV controls (Phases 1 and 2 for all boiler types) * 250 ton PSD,NSPS * RACT and NSR in non-waiver areas	* RACT at major sources in non-waiver areas * 250 ton PSD, NSPS * NSR in non-waiver areas	* Fed Phase II small engine standards * Fed Marine engine standards * Fed HDV (≥50 hp) standards-Phase1 * Fed RFG - Phase II[1] * Fed locomotive standards (in. Rebuilds) * HC engine 4 gm standard	* Tier I LDV and HDV standards * Fed RFG - Phase II[1] * Enhanced I/M[1] * Basic I/M[1] * Clean fuel fleets[1] * National LEV * HDV 3 gm standard
SR8	* SR1 plus 0.25 lb/MMBTU (IL, IN, WI, KY, MO, TN), and State rule (MI)	* SR1 plus State rule (MI)	Same as SR1	* SR1 plus Tier II/Low S
SR9	* SR1 plus 0.20 lb/MMBTU (IL, IN, WI), 0.25 lb/MMBTU (KY, MO, TN), and State rule (MI)	* SR1 plus State rule (MI)	Same as SR1	* SR1 plus Tier II/Low S
SR10	* SR1 plus 0.20 lb/MMBTU (IL, IN, WI), 0.25 lb/MMBTU (KY, MO, TN), and State rule (MI)	* SR1 plus SR12 (IL, WI), and State rule (IN, MI)	Same as SR1	* SR1 plus Tier II/Low S
SR11	* SR1 plus 0.15 lb/MMBTU (IL, IN, WI), 0.25 lb/MMBTU (KY, MO, TN), and State rule (MI)	* SR1 plus SR12 (IL,WI), and State rule (IN, MI)	Same as SR1	* SR1 plus Tier II/Low S
SR12	* 0.15 lb/MMBTU in 22 affected States	* 60% large boilers,turbines 90% large I.C. engines 30% large cement plants	Same as SR1	* SR1 plus Tier II/Low S

In mandatory areas

SR13	* SR1 plus 0.25 lb/MMBTU (IL, IN, KY, TN), and State rule (MI, MO, WI)	* SR1 plus State rule (MI, IN)	Same as SR1	SR1 plus Tier II/Low S
SR14	* 0.15 lb/MMBTU in 20 affected States * State rule (WI, MO)	* 60% large boilers,turbines 30% large cement plants	Same as SR1	* SR1 plus Tier II/Low S
SR15	* SR1 plus 0.25 lb/MMBTU (IL, IN, KY, TN), and State rule (MI, MO, WI)	* SR1 plus State rule (MI, IN)	Same as SR1	* SR1 plus Tier II/Low S
SR16	* 0.15 lb/MMBTU in 20 affected States * State rule (WI, MO)	* 60% large boilers,turbines 30% large cement plants	Same as SR1	* SR1 plus Tier II/Low S
SR17	* 0.15 lb/MMBTU in 21 affected States * State rule (WI)	* 60% large boilers,turbines 30% large cement plants	Same as SR1	* SR1 plus Tier II/Low S
VOC				
96bas	* CTG and Non-CTG RACT at major sources in NA areas * NSR LAER and Offsets in NA areas		* Fed RFG - Phase I[1]	* Fed RFG - Phase 1[1] * Enhanced I/M[1] * Basic I/M[1]
SR1	Same as 96bas		* Fed Phase II small engine standards * Fed Marine engine standards * Fed HDV (≥50 hp) standards-Phase1 * Fed RFG - Phase II[1] * C/C solvent and arch. coating controls * Stage I, II in NA areas * Autobody, degreasing, and dry cleaning controls in NA areas	* Tier I LDV and HDV standards * Fed RFG - Phase II[1] * 9.0 RVP fuel elsewhere in domain * Enhanced I/M[1] * Basic I/M[1] * Clean fuel fleets[1]
SR8 - SR17	Same as SR1		Same as SR1	SR1 plus Tier II/Low S

In mandatory areas

Table 5. Metrics for Tier II/Low S Analysis

	12 km Results									4 km Results					
	Peak Ozone (ppb)			No. Grids > 124 ppb			No. Hours > 124 ppb			Peak Ozone (ppb)		No. Grids > 124 ppb		No. Hours > 124	
DAY	SR1	SR1a	SR12	SR1	SR1a	SR12	SR1	SR1a	SR12	SR1	SR1a	SR1	SR1a	SR1	SR1a
Jun 24	91	91	90	0	0	0	0	0	0	93	93	0	0	0	0
Jun 25	116	114	113	0	0	0	0	0	0	129	125	10	4	15	4
Jun 26	126	124	119	12	9	0	20	9	0	128	127	109	28	135	32
Jun 27	118	117	113	0	0	0	0	0	0	114	113	0	0	0	0
Jun 28	98	97	95	0	0	0	0	0	0	99	98	0	0	0	0
Jul 16	104	104	103	0	0	0	0	0	0	104	104	0	0	0	0
Jul 17	88	88	90	0	0	0	0	0	0	89	89	0	0	0	0
Jul 18	106	106	107	0	0	0	0	0	0	101	101	0	0	0	0
Jul 19	113	112	110	0	0	0	0	0	0	106	106	0	0	0	0
Jul 20	138	136	130	26	23	12	102	83	38	127	127	58	39	103	52
Jul 21	128	127	125	5	3	2	10	7	3	126	125	9	3	11	5
Jun 15	79	78	74	0	0	0	0	0	0	78	78	0	0	0	0
Jun 16	92	91	85	0	0	0	0	0	0	89	88	0	0	0	0
Jun 17	110	110	106	0	0	0	0	0	0	101	101	0	0	0	0
Jun 18	109	109	109	0	0	0	0	0	0	106	106	0	0	0	0
Jun 19	110	110	110	0	0	0	0	0	0	112	111	0	0	0	0
Jun 20	112	111	110	0	0	0	0	0	0	114	114	0	0	0	0
Jun 21	122	120	120	0	0	0	0	0	0	121	118	0	0	0	0
Jun 22	131	130	121	11	7	0	30	19	0	129	128	69	22	226	42
Jun 23	125	124	116	2	1	0	4	2	0	114	113	0	0	0	0
Jun 24	128	126	127	7	3	2	14	8	5	127	125	56	3	110	3
Jun 25	120	120	122	0	0	0	0	0	0	118	118	0	0	0	0
Jul 9	75	74	73	0	0	0	0	0	0	78	78	0	0	0	0
Jul 10	85	84	79	0	0	0	0	0	0	79	78	0	0	0	0
Jul 11	88	90	90	0	0	0	0	0	0	93	93	0	0	0	0
Jul 12	107	106	103	0	0	0	0	0	0	113	112	0	0	0	0
Jul 13	131	130	128	26	20	9	71	50	20	130	129	107	82	243	169
Jul 14	130	129	128	21	19	14	67	53	21	125	125	81	51	137	58
Jul 15	136	135	135	27	22	11	87	68	34	135	135	124	105	284	206
Jul 16	121	121	117	0	0	0	0	0	0	119	119	0	0		0
Jul 17	82	81	80	0	0	0	0	0	0	83	82	0	0		0
Jul 18	54	54	53	0	0	0	0	0	0	53	54	0	0		0

Table 6. Results of Deterministic Attainment Test

Test: Pass if daily max ozone in every surface grid cell for all days ≤ 124 ppb

Results:

	96bas	SR1	SR1a	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17
6-25-91	123	116	114	113	113	113	113	113	111	110	111	110	110
6-26-91	**138**	**126**	124	122	122	121	121	119	120	117	120	117	117
6-27-91	**127**	118	117	114	114	114	114	113	112	111	112	111	111
6-28-91	102	98	97	95	95	95	95	95	93	93	96	95	95
7-16-91	108	104	104	104	104	103	103	103	104	103	104	103	103
7-17-91	89	88	88	88	89	89	90	90	87	88	89	89	89
7-18-91	108	106	106	107	106	107	106	107	104	104	109	109	109
7-19-91	112	113	112	111	111	111	111	110	110	110	112	111	111
7-20-91	**150**	**138**	**136**	**132**	**131**	**131**	**131**	**130**	**130**	**129**	**130**	**128**	**128**
6-21-95	122	122	120	120	120	120	120	120	118	118	118	118	118
6-22-95	**131**	**131**	**130**	124	124	124	124	121	122	119	122	119	119
6-23-95	**128**	**125**	124	119	119	119	119	116	116	113	116	113	113
6-24-95	**136**	**128**	**126**	**127**	**127**	**128**	**128**	**127**	123	123	**126**	**126**	**126**
6-25-95	124	120	120	121	121	122	122	122	119	119	120	120	120
7-12-95	118	107	106	104	104	104	104	103	104	103	105	105	104
7-13-95	**146**	**131**	**130**	**128**	**129**	**128**	**128**	**128**	**127**	**126**	**125**	124	124
7-14-95	**140**	**130**	**129**	**128**	**129**	**128**	**128**	**128**	**126**	**126**	**127**	**127**	**127**
7-15-95	**156**	**136**	**135**	**135**	**135**	**135**	**135**	**135**	**130**	**130**	**129**	**128**	**128**

Table 7. Results of Statistical Attainment Test

Test: Pass if meet three benchmarks. If fail one or more benchmarks, then may still pass depending on WOE determination

Benchmark 1 (Limit on number of modeled exceedances)

Requirements

Number of days with allowed exceedances in each subregion is 3 or ≤ "N" - 1 ("N" = number of severe days), whichever is less

Exceedances allowed only on "severe" days[12]

Results

Maximum number of exceedances

SR1	SR1a	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17
3	3	2	2	1	1	1	1	1	1	1	1

Exceedance days

SR1:	8	**6-26-91**	7-20-91	6-22,**23**,24-95	7-13,14,15-95
SR1a:	6		7-20-91	6-22,24-95	7-13,14,15-95
SR8-12:	5		7-20-91	6-24-95	7-13,14,15-95
SR13,14:	4		7-20-91		7-13,14,15-95

*(Note: non-severe days shown in **red** above)*

Severe days = Jul 18 - 20, 1991; Jun 19, 22, 24, 1995; Jul 12 - 15, 1995

Benchmark 2 (Limit on value of modeled exceedances)

Requirement

Modeled concentrations on severe days < 130 - 145 ppb

Results

	Rank	Allowed Value	SR1	SR1a	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17
6-25-91			116	114	113	113	113	113	113	111	110	111	110	110
6-26-91			**126**	124	122	122	121	121	119	120	117	120	117	117
6-27-91			118	117	114	114	114	114	113	112	111	112	111	111
6-28-91			98	97	95	95	95	95	95	93	93	96	95	95
7-16-91			104	104	104	104	103	103	103	104	103	104	103	103
7-17-91			88	88	88	89	89	90	90	87	88	89	89	89
7-18-91	6	144	106	106	107	106	107	106	107	104	104	109	109	109
7-19-91	47	130	113	112	111	111	111	111	110	110	110	112	111	111
7-20-91	75	130	**138**	**136**	**132**	**131**	**131**	**131**	130	130	129	130	128	128
6-21-95			122	120	120	120	120	120	120	118	118	118	118	118
6-22-95	32	130	**131**	130	124	124	124	124	121	122	119	122	119	119
6-23-95			**125**	124	119	119	119	119	116	116	113	116	113	113
6-24-95	10	139	128	126	127	127	128	128	127	123	123	126	126	126
6-25-95			120	120	121	121	122	122	122	119	119	120	120	120
7-12-95	31	130	107	106	104	104	104	104	103	104	103	105	105	104
7-13-95	12	137	131	130	128	129	128	128	128	127	126	125	124	124
7-14-95	5	146	130	129	128	129	128	128	128	126	126	127	127	127
7-15-95	16	135	**136**	135	135	135	135	135	135	130	130	129	128	128

Benchmark 3 (Required minimum level of improvement)

Requirement

Number of grid cell hours > 124 ppb must be reduced by 80% on severe days
(required only on days > 5% underprediction)

Results

	Rank	% Improvement (No. Grid Cell Hours > 124 ppb) SR1	SR1a	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17
6-25-91													
6-26-91		87	94	100	100	100	100	100	100	100	100	100	100
6-27-91		100	100	100	100	100	100	100	100	100	100	100	100
6-28-91													
7-16-91													
7-17-91													
7-18-91	6												
7-19-91	47												
7-20-91	75	**75**	80	88	89	89	89	91	89	92	92	93	94
6-21-95													
6-22-95	32	**6**	**41**	94	91	91	91	100	100	100	100	100	100
6-23-95		**67**	83	100	100	100	100	100	100	100	100	100	100
6-24-95	10	**70**	83	89	89	89	87	89	100	100	96	98	98
6-25-95		100	100	100	100	100	100	100	100	100	100	100	100
7-12-95	31												
7-13-95	12	83	88	94	93	95	95	95	96	97	98	100	100
7-14-95	5	**77**	82	92	89	91	92	93	98	98	97	98	98
7-15-95	16	**74**	80	85	86	88	89	90	97	97	99	99	99

Table 8. Results of 8-Hour Relative Attainment Test

SITE	Base	SR1	SR1a	SR8	SR8a	SR9	SR10	SR11	SR12	SR12a	SR12b
Pleasant Prairie	97		95	93					93	92	92
Kenosha	86		84	83					82	82	82
Racine	92		90	89					88	88	88
S. Milwaukee	93		89	88					87	86	86
Milwaukee-Alverno	88		84	83					82	81	82
Milwaukee-UWMN	88		85	84					84	84	83
Milwaukee-Bayside	93		90	88					87	87	87
Grafton	92		89	87					86	85	86
Harrington Beach	93		90	88					87	86	86
Sheboygan	93		90	88					87	86	86
Manitowoc	97		94	92					91	90	90
Kewaunee	94		91	89					88	87	88
Newport Beach	97		93	91					90	89	89
Beloit	87		79	76					76	75	75
Jefferson	85		81	79					79	78	79
Zion	85		83	82					81	81	81
Waukegan	88		85	84					84	84	84
Northbrook	86										
Cary	85		85	84					84	84	82
Elgin	85		86	85					85	85	83
Des Plaines	87		88	88					89	89	87
Evanston	91		87	86					86	85	86
Univ. of Chicago	85		81	80					79	79	79
Chicago-SWFP	89		84	83					83	82	82
Chicago-Jardine	89		85	84					83	83	83
Hammond	96		91	90					90	89	89
Gary-IITRI	94		89	88					88	87	87
Ogden Dunes	97		92	91					91	90	90
National Lakeshore	96		92	91					90	89	90
Michigan City	104		100	98					97	97	97
Laporte	88										
Lowell	89										
Valparaiso	87										
Potato Creek	91		88	86					84	83	83
South Bend	89		85	83					81	81	81
Granger	92		88	87					85	84	84
Bristol	90		87	85					83	83	83
Frankfort	88		86	84					83	82	83
Scottville	96		94	92					91	90	90
Muskegon	99		96	94					92	92	92
Holland	98		94	93					92	91	91
Jenison	85		81	80					79	78	79
Grand Rapids	86		82	81					80	80	80
Evans	88		85	84					83	83	83
Coloma	98		94	92					91	90	91
Cassopolis	94		90	88					86	86	86
Kalamazoo	87		83	81					80	80	80